



U.S. Department of Energy FreedomCAR & Vehicle Technologies Program

Advanced Vehicle Testing Activity

Real-World Research and Testing: Producing and Using Hydrogen in Transportation

*HydroVision 2006 – The Hydrogen Economy
Portland, Oregon
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INL/CON-06-11577

Presentation Outline

- **Background & Goal**
- **Arizona Public Service (APS) Alternative Fuel (Hydrogen) Pilot Plant - design & operations**
 - **Hydrogen subsystem**
 - **CNG subsystem**
 - **Safety system**
- **Fuel Dispensing**
- **Hydrogen & HCNG Internal Combustion Engine (ICE) Vehicle Testing Activities**
- **WWW Information**

AVTA Background & Goal

- **Advanced Vehicle Testing Activity (AVTA) is part of the U.S. Department of Energy's (DOE) FreedomCAR and Vehicle Technologies Program**
- **These activities are conducted by the Idaho National Laboratory (INL) & the AVTA testing partner Electric Transportation Applications (ETA)**
- **AVTA Goal - Provide benchmark data for technology modeling, research & development programs, as well as help fleet managers & other vehicle purchasers make informed purchase & operations decisions**

AVTA Testing History

- **Full-size pure EVs (40 models, 5 million test miles)**
- **Neighborhood EVs (15 models)**
- **Urban EVs (3 models, 1.75 million test miles)**
- **Hybrid EVs (11 models, 32 HEVs, 2 million miles)**
- **Hydrogen ICE vehicles (several models, 300k miles)**
- **Oil bypass filter testing (17 vehicles, 1.3 million miles)**
- **Dynamometer, track & fleet testing**



APS Alternative Fuel (Hydrogen) Pilot Plant

- **Partners - Arizona Public Service (APS), ETA, INL, & DOE**
- **First & longest operating hydrogen station in the U.S. – since June 2002**
- **Hydrogen produced onsite**
- **Hydrogen & CNG fueling**

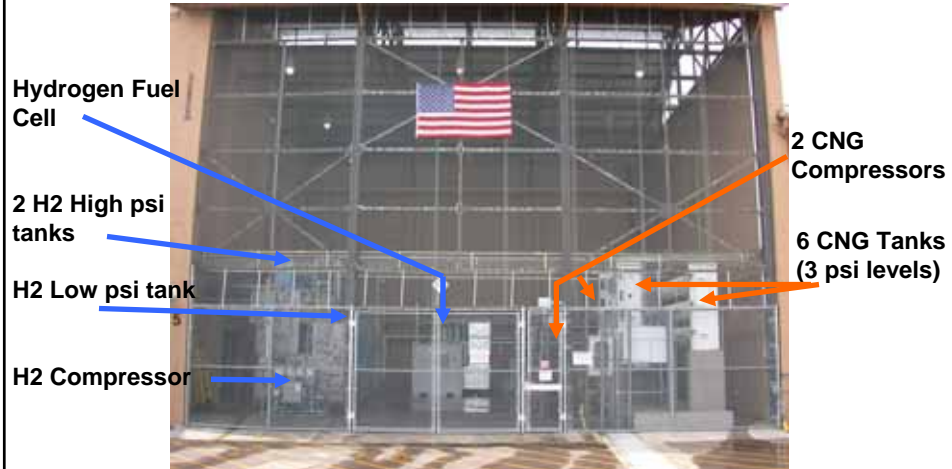


Pilot Plant & Hydrogen ICE Vehicle Testing Objectives

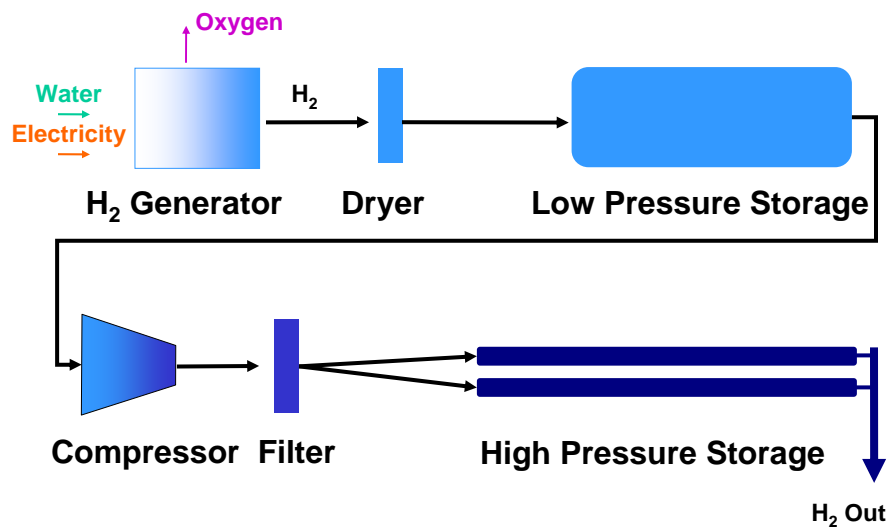
- **Evaluate the safety & reliability of operating ICE vehicles on 100% hydrogen & hydrogen/compressed natural gas (HCNG) blended fuels (15 to 50% HCNG)**
- **Evaluate hydrogen fueling infrastructure operations & costs**
- **Quantify hydrogen & HCNG ICE vehicle costs, performance & emissions**



Pilot Plant - Layout



Pilot Plant - Hydrogen Subsystem



Pilot Plant – Hydrogen Subsystem

- Proton Energy Systems' HOGAN PEM stationary fuel cell operating in reverse
 - 300 scfh hydrogen output @ 150 psi
 - 17 kWh per 100 scf hydrogen
- Hydrogen Lector dryer
 - -80°F dew point
- Pressure Dynamic Consultants (Pdc Machines)
 - 300 scfh @ 6,100 psi
- 8 Norman hydrogen filter locations
- Hydrogen - 99.9997% purity

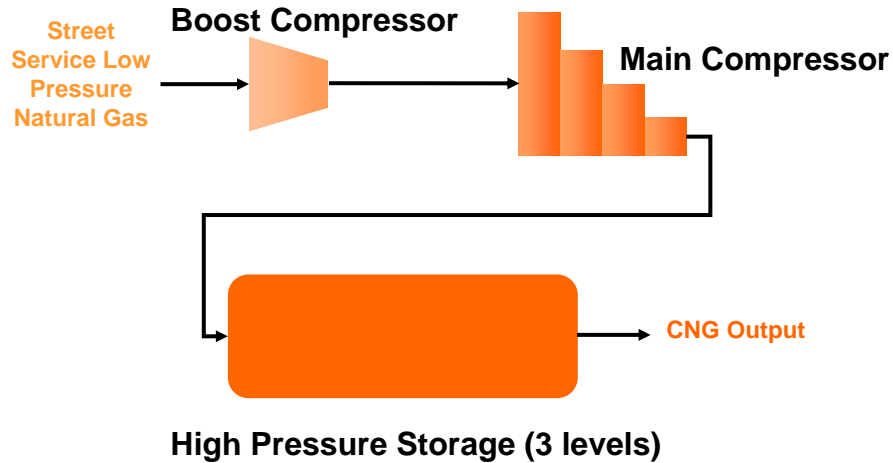


Pilot Plant - Hydrogen Storage

- Low pressure hydrogen storage (lower tank) - 8,955 SCF @ 150 psi
- High pressure hydrogen storage (upper 2 tanks) - 17,386 SCF @ 6,000 psi (total both tanks)



Pilot Plant - CNG Substation



Pilot Plant - CNG System

- **CNG Boost Compressor**
 - 300 scfm @ 60 psi
- **CNG Main Compressor**
 - 350 scfm @ 5,000 psi
- **CNG Storage/Pressure – 6 tanks**
 - 3 Low: 11,079 scf @ 3,600 psi
 - 2 Medium: 5,711 scf @ 4,500 psi
 - 1 High: 5,711 scf @ 5,000 psi
 - Manufacturer: CP Industries



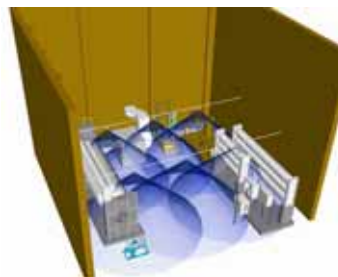
Pilot Plant - Emergency Shutdown System

- Ultra-fast IR/UV detectors
- Combustible gas detectors
- Manual (5) & remote trips
- Vent stack temperature monitor
- Alarms horns & strobe lights
- Vent stack fire suppression



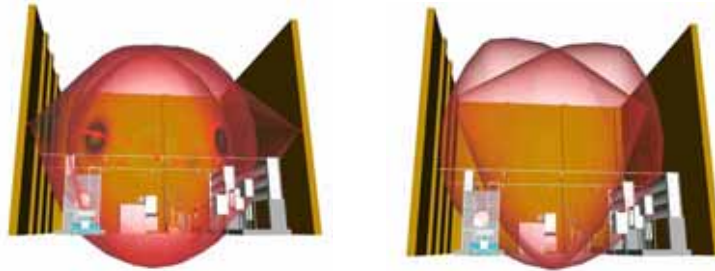
Pilot Plant – Hydrogen Gas Detectors

- Six combustible gas detectors (Det-Tronics RS 8471)
- Monitors hydrogen & natural gas in 1% increments of lower flammability limits (LFL)
- Alarm condition at 25% of LFL reached
- Emergency shutdown when 50% of LFL reached

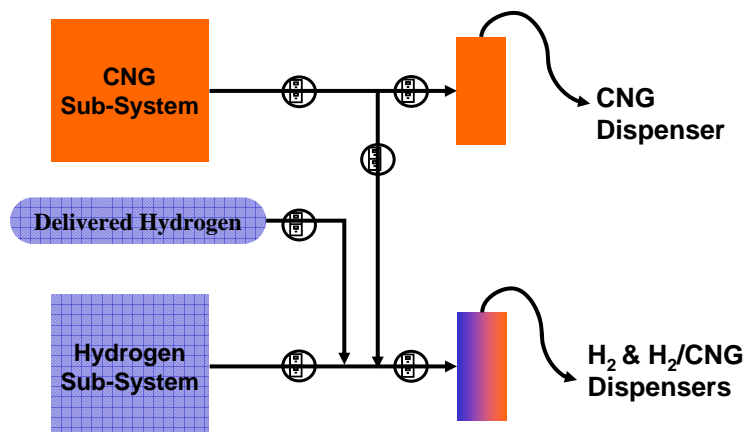


Pilot Plant – Flame Detectors

- Two mid-level (35 feet) & four corner IR/UV flame detectors (Spectrex 20/20LB units)
- One detector at fuel dispenser unit
- If flame detected, emergency shutdown initiated within 3 milliseconds



Pilot Plant – Dispenser System



Pilot Plant - Fueling Dispensers

- Includes metering & electronic billing interface
- Fully permitted for motor fuel dispensing
- Public access



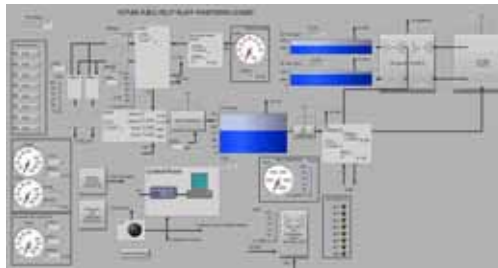
Prototype Dispenser Testing

- Uses proportional flow control valves for hydrogen & CNG gas streams from 100 to 40,000 scfh
- Real-time ratio control of blended fuels - uses coriolis mass flow transducers in hydrogen & CNG gas streams
- 1 Nozzle - CNG & HCNG fuels (15, 20, 30, & 50% hydrogen by volume) at 3,600 psi
- 1 Nozzle - 100% hydrogen at 5,000 psig
- Being commercialized by Clean Energy



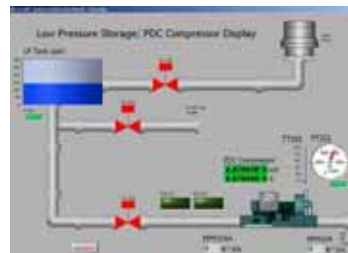
Pilot Plant - Monitoring

- Real-time station & component monitoring at 100 nodes
- Fuel quantities & costs collected for pure hydrogen and HCNG blended fuels
- Electric power equipment
 - Voltages & currents
- Select process temperatures
- Major process parameters
 - Pressures & flows



Pilot Plant - Monitoring

- 545 Hydrogen, 3,940 HCNG, & 6,810 CNG fueling events & 8,600 kg of hydrogen produced (6/30/06)
- Hydrogen kg energy costs based on historical (26% to 49%) & projected (70%) plant factors
 - \$3.43 down (26% PF) to \$2.39 per kg (70% PF)
 - DOE 2005 energy cost target \$2.47
- Water cost per kg of hydrogen \$0.10



Hydrogen & HCNG ICE Vehicle Testing

- Initial ICE hydrogen & HCNG vehicle testing
 - Dodge van on 15% HCNG (operating)
 - Ford F150 up to 30% HCNG (operating)
 - Ford F150 up to 50% HCNG (testing complete)
 - 100% hydrogen Mercedes Benz van (operating)
- Total of 300,000 hydrogen & HCNG miles



15% HCNG Dodge Van Emissions Testing

- 5.2 L CNG V8 (no modifications) with 71,000 HCNG test miles - no problems
- 27,000 miles of 15% HCNG fuel data - 15.5 miles/GGE

Percentage change in 15% HCNG emissions compared to 100% CNG emissions

Total hydrocarbons	-34.7%
Carbon monoxide	-55.4%
Oxides of nitrogen	+92.1%
Carbon dioxide	-11.3%



30% HCNG F150 Testing

- 5.4 L V8 CNG engine – added: supercharger, ignition modifications & exhaust gas recirculator
- Fleet testing - 59,000 30% HCNG miles: 17.3 miles/GGE

Fuel Blend	0 to 60 mph (secs.)	Miles/GGE	Range (miles)
CNG	10.10	23.3	122
15% HCNG	10.97	22.6	110
30% HCNG	12.68	23.5	102



30% HCNG F150 Emissions Testing

Fuel Type	Percentage Change in Emissions Testing					
	NMHC	CH ₄	HC	CO	NO _x	CO ₂
Gasoline	Base	Base	Base	Base	Base	Base
CNG	-80	+967	+35	-63	-34	-24
15% HCNG	-78	+1000	+40	-70	-26	-27
30% HCNG	-89	+1050	+37	-73	-25	-28

NMHC=Non-Methane Hydrocarbons
 HC=Total Hydrocarbons
 NOx=Oxides of Nitrogen

CH₄=Methane
 CO=Carbon Monoxide
 CO₂=Carbon Dioxide



50% HCNG F150 Emissions Testing

- **Modifications**

- SVO heads, exhaust intercooler & supercharger
- Exhaust gas recirculator & ignition modification
- Equipped with 3 Quantum hydrogen 3,600 psi tanks with 3 kg total storage

Percent reduction in emissions (HCNG versus gasoline-fueled F-150)

HC	CO	NO _x	CO ₂
-3.5%	-43.3%	-97.0%	-16.7%

HC = total hydrocarbons
CO = carbon monoxide
CO₂ = carbon dioxide
NO_x = oxides of nitrogen



HCNG ICE Vehicle Fleet Operations

- **APS meter reader fleet 12 Bifuel vehicles (GM)**
 - 1,600 fueling events, 190,000 miles using 10,600 GGE of 15% HCNG
- **Public Fleet - private party Bifuel conversions**
 - 350 fueling events, 36,000 miles (estimated) using 1,800 GGE of HCNG blends (mostly 15%)



5.4L 16-valve 100% Hydrogen ICE Vehicle

- 5.4L V-8, 100% hydrogen 16-valve Ford/ETEC pickup
- 5 speed transmission, supercharged (3 psi boost), hydrogen fuel injectors, & air-to-water intercooler
- Hardened valves & seats, & forged pistons with 12:1 compression
- Motec fuel & spark controls, lean-burn mode
- Onboard hydrogen storage 3 Dynetek tanks @ 3,000 psi, 6.5 kilograms, aluminum vessel & fiberglass wrap
- Converted by ETEC
- 1,365 lbs payload



5.4L 16-valve 100% Hydrogen ICE Vehicle

- **Baseline Performance testing results**
 - Max speed @ 1 mile: 81 mph & ¼ mile: 58 mph
 - Acceleration (0 to 50 mph): 18.1 seconds
 - SAE J1634 fuel economy (AC on): 14.5 miles/GGE
 - SAE J1634 fuel economy (AC off): 18.0 miles/GGE
 - 45 mph constant speed: 27.0 miles/GGE
 - Range 95 (14.5 miles/GGE) to 175 miles (27 miles/GGE)
- **Fleet testing – 5,200 miles: 17.4 miles/GGE (110 miles range)**



5.4L 32-valve 100% Hydrogen ICE Vehicle

- 5.4L V-8, 100% hydrogen 32-valve Ford/ETEC pickup
- Automatic transmission, hydrogen fuel injectors, 12 pounds supercharger boost & air-to-air intercooler
- Hardened valves & seats, & forged pistons with 11.5:1 compression
- Motec fuel & spark controls, lean-burn mode
- 8,000 fleet testing miles - 14.4 miles/GGE
- Onboard hydrogen storage 3 Dynetek tanks @ 5,000 psi, 15.3 kilograms (230 miles range)
- Converted by ETEC



6L V-8 100% Hydrogen ICE Vehicle

- Base vehicle: Chevrolet 1500HD crew cab (4 door) with 6L V8 CNG engine
- Converted by ETEC/Roush to 100% hydrogen
- 4-speed automatic transmission, electronic port fuel injection, supercharger, liquid-to-air intercooler
- Integration of powertrain control module & development of hydrogen lean-burn control strategies
- Implementation of J1850 communications to maintain seamless integration with existing OEM equipment



6L V-8 100% Hydrogen ICE Vehicle

- 10.5 kg 100% hydrogen storage onboard @ 5,000 psi
- 200 Horsepower & 260 lb-ft torque
- Preliminary Argonne dynamometer results
 - 20 miles highway & 14 miles city per GGE
 - Range 140 to 200 miles
 - THC 0.0005 g/mi, NOx 0.0610 g/mi, CO 0.0685 g/mi, & CO₂ 0.0926 g/mi
- Nine vehicles produced
- 8 units to Vancouver B.C.



Acknowledgement

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Additional Information

<http://avt.inl.gov>

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